Performance Investigation of Ku-bands Adaptive Sigma-Delta Modulation for Small Satellite Transceivers

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Abstract: In this work, a design and implementation of wideband low noise Adaptive Sigma Delta Modulation (ASDM) system is presented. The design and implementation are achieved by using the following components: Analog to Digital Converter (ADC) for radio Wireless Local Area Network (WLAN), and a single Small Parabolic Reflector Antenna (SPRA) for satellite transmitting and receiving signals simultaneously, where the SPRA satisfying the reciprocity theorem. The proposed behavioral ASDM system for satellite radio transceivers utilizes employs a forth order cascaded adaptive sigma delta modulator to achieve the desired oversampling ratio and high resolution. Operational Transconductance Amplifier (OTA) based on CMOS technology is used to design the proposed modulator. Wideband Intermediate Frequency (IF) double conversion super-heterodyne transmitter and receiver were chosen to improve the performance. The performance investigation is realized under MATLAB/Simulink software. The Calculation and Simulation results show a good Image rejection selectivity, and improve the power flux density of the (SPRA) antenna.

Keywords: performance investigation, ASDM system, ADC, WLAN, Small Parabolic Reflector Antenna, OTAs, power flux density.

1. Introduction

Sigma delta modulation with cascaded stages have been proposed by [1-2]. The proposed approach utilizing both digital correction method and improving the sensitivity of OTAs adaptation circuits used in high precession analogue design. As a result the design and architecture modulator circuit were improved.

Achieving high resolution and large bandwidth is accomplished using high-order adaptive sigma delta modulators. In addition to that, the slope-overload distortion for any varying input signal and the higher-order noise shaping function was realized using cascaded second order SDM. These circuits are sensitive to analog circuit imperfections which depend on the usage of good matching circuits between the digital output and the analog filter. A prominent problem of the design of cascaded delta sigma modulation is the leakage of quantization noise which should be reduced in the analog or digital estimation circuit design.

Sigma delta quantization technique estimates the quantization error of the first stage, which is quantized by multibit in the second stage. Also this modulator requires mismatch-shaping DAC in the first stage. Cancellation of the imperfect error causes the leakage of the quantization noise. To reduce the leakage, sigma delta modulation with second order cascaded stages are used. In the first stage of a DAC of 1-1.5-bit is applied where a DAC of 8-12-bit is applied in the second stage. In addition to that, an adaptive digital FIR filter is applied in second stage to more reduce the noise [2 -3].

This work, investigates the performance higher order of ASDM, mainly the forth-order cascaded modulator.

Each section consists of adaptive quantization modulator with backward estimation, by feedback the output encoded signal through the adaptation scheme to give the continuously estimating of the amplitude of the quantized input signal, with low OSR equal 16. The output pulse of encoded signal feedback through adaptation scheme, which consists of low pass filter followed by rectifier based on OTAs, which controlled voltage gain to continuously estimating the amplitude of sampling instantaneously (Time varying the step size) to eliminate the varying input signal. If the input signal X(n) is rapidly increasing or decreasing, the output encoded pulses Y(n) are all 1s or all 0s, therefore the magnitude of the filter output will be relatively large. This will control the amount of the amplifier bias current, which will vary the trans conductance (g_m), then the voltage gain of the amplifier (A_v), which means time varying step size $\Delta(n)$ [1-3].

Many researchers have used SCC containing admixtures to satisfy the great demand for fines needed for this type of concrete, thereby improving its mechanical, rheological and durability properties in comparison with normal vibrated concrete (NVC). Siddique [5] investigated the properties of SCC made with different amounts of fly ash. El-Dieb [6] studied mechanical and durability properties of ultra high strength-fiber reinforced concrete (UHS-FRC) with self compacting characteristics. According to Fava et al. [7], in SCCs with ground granulated blast furnace slag (GGBFS), strength increase can be achieved. Kulakowski et al. [8] reviewed the silica fume influence on reinforcement corrosion in concrete and the effect of metakaolin on transport properties of concrete were also investigated by Shekarchi et al [9]. There are several works on incorporating nanoparticles into concrete specimens to achieve improved physical and mechanical properties such as using SiO_2 nanoparticles in mortars and cement-based materials [10–12], normal concrete [13,14] and high performance self compacting concrete [15].

Incorporating of TiO_2 nanoparticles has been addressed in some of the works considering the properties of NVCs [16]. The flexural fatigue performance of concrete containing TiO_2 nanoparticles for pavement has experimentally been studied by Li et al. [17]. They showed that the flexural fatigue performance of concretes containing TiO2 nanoparticles is improved significantly and the sensitivity of their fatigue lives to the change of stress is also increased. In addition, the theoretic fatigue lives of concretes containing TiO_2 nanoparticles are enhanced in different extent. With increasing stress level, the enhanced extent of theoretic fatigue number is increased [17].

2. Overview

In practical applications, cascaded forth-order Adaptive sigma-delta modulation topology with improved signal to noise ratio (SNR) and reduced sensitivity to the integrator nonlinearities is shown in Fig.1

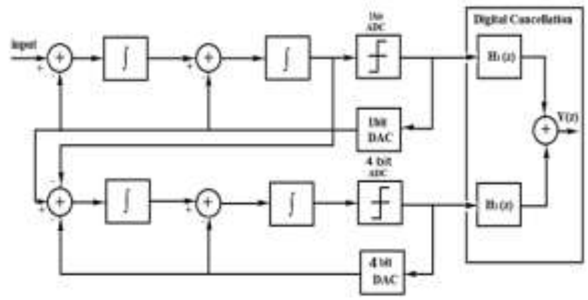

Fig. 1. Block diagram of cascaded ASDM for satellite network

For many years many researchers have attempted to invalidate this assumption. Various designs [4,5] have been proposed to build wideband Adaptive Sigma-Delta Converters in super-heterodyne transceivers. The Conventional designs have made significant progress on the sigma delta ADCs which are widely used in wireless communication systems [6,7]. These designs use direct conversion, and double conversion super-heterodyne for radio specification of WLAN 802.11b receiver. The system design multi standard wireless systems, Wireless transmitters and receivers are required to increase the data rate, while reducing the power consumption [8,9].

The output of ASDM receiver is generated by integrating the quantization output to form the (stair step) approximation m_s (t) which is given by

$$ms\ (t) = \sum_{n=-\infty}^{\infty} (nTs) \int \delta(\alpha - nTs)\, d\alpha \qquad (1)$$

The weight of step size $\Delta(nTs)$ can be controlled (increased or decreased rapidly) by the variable gain (Av) of OTAs in adaptive circuits. This is effective for oversampling ratio to reduce the granular noise and slope overload distortion [3,10]. So, the SNR is the ratio between signal power and the quantization noise that can be calculated from the performance equation.

$$\text{SNR (dB)} = 6.02\, N + 1.76 + 10 \log \left(\frac{A}{Amax}\right)^2 \quad (2)$$

Where N is the resolution N = 1 or 4 bits, A is the peak input amplitude, and $Amax$ is the maximum non overloaded amplitude.

This work focuses on the small receiver earth station, with small Antenna (SPRA), and super-heterodyne architecture, with variable IF. The paper is arranged as follows:

In current section the most important, and developed transceivers design is discussed. The second section presents superhetrodyne radio receiver, third section calculation and simulation results, forth section SPRA transceivers calculation, and in the last section concludes the paper.

III. Research methodology

In the block diagram of super-heterodyne transmitter and receiver small earth Station, using Small Parabolic Reflector Antenna (SPRA) with diameter from 0.6 m to 3 m is proposed for satellite communications to receive and transmit the Super High frequency (SHF) Ku-band signals. In this study, for precision analysis and simulation, only one frequency from Ku–band system is chosen. For the up-link frequency band (17.3-17.8) GHz, the allocation for high power is chosen at 17.8GHz whereas for the down-link frequency band (12.2-12.7) GHz, the allocation for high power is chosen at 12.7GHz.

The block diagram of double conversion superheterodyne for small satellite transmitter and receiver is shown in Fig. 2.

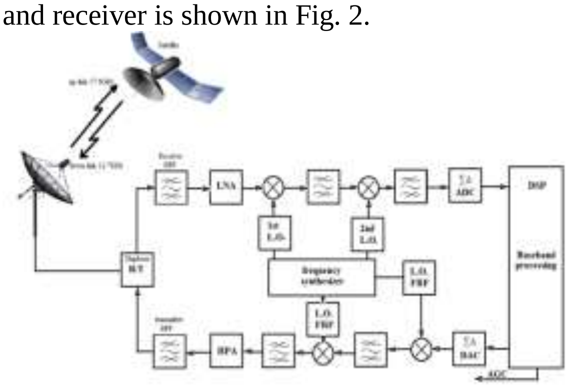

Fig.2. The Proposed block diagram of double conversion superheterodyne Transceivers

The received down-link radio frequency band (12.2- 12.7) GHz signal with bandwidth typically of 500 MHz is amplified by an image-rejecting Low Noise Amplifier (LNA) to ensure that good SNR is achieved. Also, it provides tuning on the required radio frequency and a good selectivity using a wideband IF double–conversion superheterodyne transmitter and receiver. The signal is mixed down to high intermediate frequency f_{IF} = (1.742 to 1.814) GHz, so the local oscillator frequency for low–side tuning is f_{LO} = (10.457 to 10.885) GHz. The image frequency is f_{im} = (8.7144 to 9.071) GHz, so the difference between the wanted frequency and the unwanted image frequency is high, and there is no need for an image rejection filter to provide high levels of rejection as shown in Fig.3.

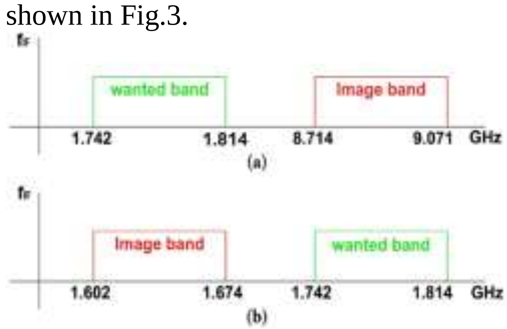

Fig.3. Low side tuning bandwidth for a) first intermediate frequency , b) Second intermediate frequency

At the output of the second down–converter, the signal frequency is the intermediate frequency for one satellite channel select which is usually 70 MHz, (or 10.7 MHz for FM radio receiver). Therefore, the frequencies of local oscillator for high–side tuning ($f_{LO} = f_{RF} + f_{IF}$) are 1.812 GHz as lower frequency and 1.884 GHz as upper frequency. Also for low side tuning ($f_{LO} = f_{RF} - f_{IF}$) the frequency are 1.672 GHz as lower frequency and 1.744 GHz as upper frequency.

The best tuning range of local oscillator frequency is 1 to 1. The frequency synthesizer provides different frequencies including voltage-controlled oscillator.

V. Calculation and Simulation Results

Using Matlab/Simulink simulation we try to belt a good model for our proposed system.So that the simulation model for dual intermediate frequency receiver system shown in Fig. 4,

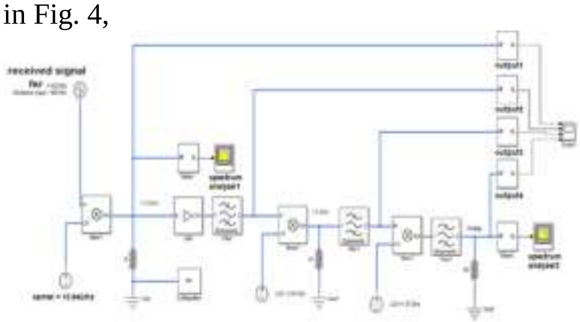

Fig.4. Simulink block diagram for dual intermediate frequency receiver system

Where the oscilloscope waveforms for the proposed simulation circuit for high frequency input modulated signal, the output of LNA, the output of the first mixer, and the signal after the second intermediate frequency band pass filter are shown in Fig. 5.

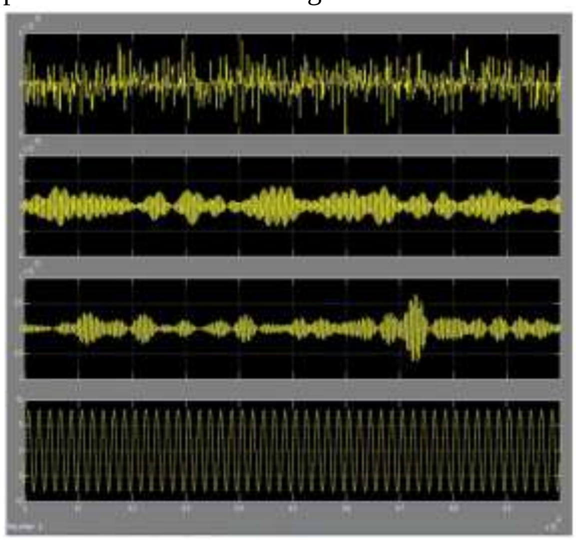

Fig.5. Input and output RF waveform for the proposed simulation circuit

From the spectrum analyzer waveform for the proposed simulation circuit shown in Fig. 6, we show a good similarity (with slop = 0.002ms) for the input and output amplitude spectrum.

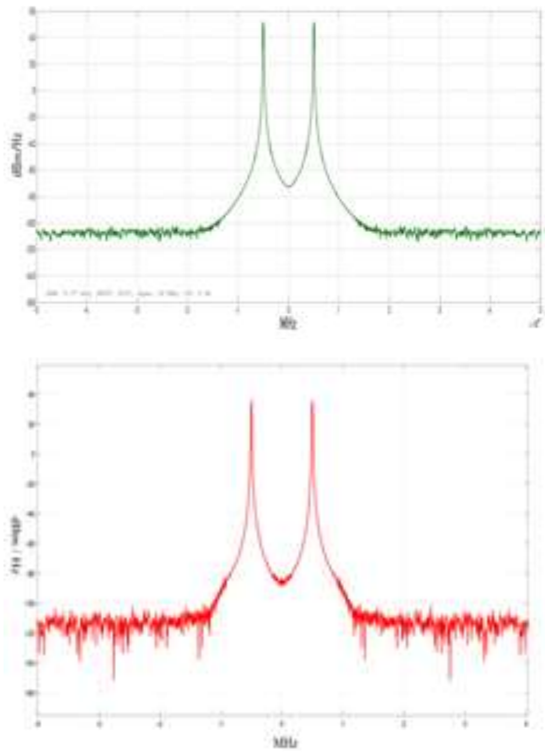

Fig.6. Input and output amplitude spectrum for the proposed simulation circuit

The SD/ADC converts f_{IF} signal into digital form, using Operational Transconductance Amplifier (OTA/CMOS technology), and the output is applied to digital signal processing (DSP) where the original baseband signal is obtained.

From DSP output, the baseband signal by converting up to (17.3 - 17.8) GHz, it is amplified by HPA and it is sent to the antenna through a duplexer.

IV. SPRA Transceivers Calculations

The proposed SPRA's are the most commonly used in satellite communication systems. The antenna provides the maximum gain to concentrate the electromagnetic wave in a given direction (Seyfollab S.et all 1999, Scott K.et all 2006, and Dennis Roddy 2006). The design of SPRA is depending on required coverage area, in the far field (Fraunhofer) region, where the radiated fields from transverse electro–magnetic radio waves for satellite communications are decreased with the increase of distance from the antenna.

The half–power beam width (3dB beam width) is given by[reference]

$$\alpha_{3dB} = K \frac{\lambda}{D} \quad (3)$$

where $k = 65^o - 75^o$, is the antenna taper factor, λ is the wave length of the transverse electromagnetic wave. For K_u band, the up-link frequency is given by

$$\lambda = \frac{c}{f} = \frac{3x10^8}{12.7x10^9} = 0.023m \quad (4)$$

So the half power beam width is

$$\alpha_{3dB} = k\frac{\lambda}{D} = 65\ \frac{0.023m}{3m} = 0.5^o$$

The maximum antenna gain is proportional to its area where the effective area of the aperture plan is

$$A = \eta\frac{\pi D^2}{4} \quad (6)$$

where η (0.5-0.8) is antenna efficiency and D is small aperture diameter.

The maximum gain is

$$G = \eta\ \frac{4\pi}{\lambda^2}\ .A = \eta\left(\frac{\pi D}{\lambda}\right)^2 \quad (7)$$

$$= 0.7 \quad \left(\frac{\pi.3m}{0.023m}\right)^2 = 117539$$

G_{dB} = 10 Log(117539) = 50.7 dB

From the results for SPRA calculation, the narrow beam width is 0.5°, as seen from the 36.000 km geostationary orbit height with gain of 50 dB which covered a small area on the earth (Seyfollab S.et all 1999,and Scott K.et all 2006) ,to express the performance of the satellite communication links.

The Transmitted power flux density $\emptyset t$ of a satellite radio wave is

$$\emptyset t = \frac{G\ Pt}{4\pi d^2} = \frac{EIRPt}{4\pi d^2} \quad (8)$$

where P_t is the transmitted power of the antenna, *d* is the range of distance and EIRP is the equivalent isotropic radiated power. So EIRB is the maximum power flux density at distance *d* from a transmit antenna with gain *G* to the Satellite.

$$EIRP = G\ P_t \quad (9)$$

$$[EIRP] = [G] + [P_t] = \text{in dBW} \quad (10)$$

The HPA converts f_{IF} to f_{RF}, so the up-link frequency 17.8 GHz with transmit power of 90 W and antenna gain of 50.7 dB. Therefore,

$$[EIRP] = 10\log\left(\frac{90W}{1W}\right) + 50.7dB \quad (11)$$

= 19.5 dBW + 50.7dB = 70.2 dBW.

(5)

Conclusions

The noise leakage is cancelled by using adaptive analog circuits. The modulator employs 1-bit level quantization and 4-bits quantization in the final stage of 2-2 cascaded circuit, so the increase SNR at oversampling ratio achieved using adaptive circuit for each cascaded stage A brief overview of the proposed ASDC, and Small Parabolic Reflector Antenna (SPRA) was introduced, for optimal design of wide band double superheterodyne satellite transmitter and receiver, in which high IF frequency improves the performance and the image rejection.

The calculations and simulation results obtained for the ASDM/ADC will achieve a peak SNR of 98 dB for N = 4 bits. Also for SPRA antenna the product of the transmit power for up-link frequency 17.8 GHz, the [EIRP] equals 70.2 dBW. Which is most suitable for small satellite radio transceivers.

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